

Acoustic Propagation Studies in the Windy Islands Soliton Experiment (WISE)

Ching-Sang Chiu

Department of Oceanography

Naval Postgraduate School

Monterey, CA 93943-5001

Phone: (831) 656-3239

Fax: (831) 656-7970 E-mail: chiu@nps.edu

D. Benjamin Reeder

Department of Oceanography

Naval Postgraduate School

Monterey, CA 93943-5001

Phone: (831) 656-3268

Fax: (831) 656-2712 E-mail: dbreeder@nps.edu

Award #: N0001405WR20201

LONG-TERM GOAL

Our long-term research objectives are:

- (1) The characterization of meso to internal-wave-scale oceanographic processes that influence broadband sound transmissions in a coastal environment. Central to the characterization are the formulation of accurate forward relations and the quantification of the sensitivities and variability of the various observable acoustic quantities in relation to environmental differences and changes.
- (2) The development and improvement of high-resolution tomographic inverse techniques for measuring the dynamics and kinematics of meso and finer-scale sound speed structure and ocean currents in coastal regions.
- (3) The understanding of three-dimensional sound propagation physics including horizontal refraction and azimuthal coupling and the quantification of the importance of these complex physics in the prediction of sound signals transmitted over highly variable littoral regions.

OBJECTIVES

This effort is part of a large, international program called the Windy Islands Soliton Experiment (WISE). In collaboration and coordination with other U.S. and Taiwan investigators participating in WISE, we are carrying out rigorous measurements and analysis of nonlinear internal waves and their effects on low frequency acoustic propagation in the Northeastern (NE) South China Sea (SCS).

The WISE program has two separate sound transmission experiments, one over the shallow shelf and one across the deep basin along a physical oceanography mooring transect. The objective of the shelf transmission experiment is to study the physics of sound propagation through nonlinear, elevation internal waves in shallow water, and to quantify the associated fluctuations in the sound intensity. The objective of the basin transmission experiment is to study and characterize the supertidal-to-seasonal-

Report Documentation Page			Form Approved OMB No. 0704-0188	
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1. REPORT DATE 30 SEP 2005	2. REPORT TYPE	3. DATES COVERED 00-00-2005 to 00-00-2005		
4. TITLE AND SUBTITLE Acoustic Propagation Studies in the Windy Islands Soliton Experiment (WISE)			5a. CONTRACT NUMBER	
			5b. GRANT NUMBER	
			5c. PROGRAM ELEMENT NUMBER	
6. AUTHOR(S)			5d. PROJECT NUMBER	
			5e. TASK NUMBER	
			5f. WORK UNIT NUMBER	
7. PERFORMING ORGANIZATION NAME(S) AND ADDRESS(ES) Naval Postgraduate School, Department of Oceanography, Monterey, CA, 93943			8. PERFORMING ORGANIZATION REPORT NUMBER	
9. SPONSORING/MONITORING AGENCY NAME(S) AND ADDRESS(ES)			10. SPONSOR/MONITOR'S ACRONYM(S)	
			11. SPONSOR/MONITOR'S REPORT NUMBER(S)	
12. DISTRIBUTION/AVAILABILITY STATEMENT Approved for public release; distribution unlimited				
13. SUPPLEMENTARY NOTES code 1 only				
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15. SUBJECT TERMS				
16. SECURITY CLASSIFICATION OF:			17. LIMITATION OF ABSTRACT Same as Report (SAR)	18. NUMBER OF PAGES 6
a. REPORT unclassified	b. ABSTRACT unclassified	c. THIS PAGE unclassified		

scale impacts of the transbasin, nonlinear internal waves on long-range transmission loss, and to help monitor the evolution of the transbasin internal waves in the basin's interior.

APPROACH

The shelf transmission was carried out prior to the basin transmission in April 2005. This was a short, 3-day experiment to study the effects of nonlinear elevation waves on acoustic propagation. The approach was to make simultaneous, high-resolution observations of both the acoustic propagation and physical oceanography in the experimental site. Both moored and shipboard oceanographic observations were made, with sufficient spatial and temporal resolution. Simultaneously, acoustic signal transmissions, aiming at achieving sufficient realizations and spatial coverage through the internal waves, from both a moored source and mobile sources to a moored vertical line array (VLA) of hydrophones as well as sonobuoys were performed.

The analysis of the shallow-water data has commenced soon after the 2005 April cruise. The VLA data was first pulse-compressed and motion-compensated, and then analyzed for sound intensity as a function of depth and time. Characterizations of the observed intensity fluctuations, in terms of both phenomenology and statistics, will then be made. In parallel, the oceanographic measurements obtained along the transmission paths have been analyzed using empirical-decomposition and time-series methods to deduce the space-time structure of the sound-speed changes produced by the elevation internal waves. Finally, a coupled normal-mode model will be employed to examine the propagation physics by linking the observed sound-speed structure to the observed features and statistical properties of the intensity fluctuations.

The basin transmission experiment has commenced right after the completion of the shelf transmission. Major equipments for the basin experiment consist of two acoustic transceivers on integrated acoustic and physical oceanography moorings. The two transceivers will both transmit and receive phase-modulated signals for a period of one year, from Spring 2005 to Spring 2006, to capture multi-scale variability in the transmission loss. A hypothesis under this investigation is that a major portion of this acoustic variability is induced by the evolutions of the transbasin internal tides and waves that are modulated by mesoscale events and seasonal cycles. The length of this proposed reciprocal transmission path is approximately 150 km across the NE SCS basin.

The analysis of the basin transmission will commence in 2006, after retrieval of the midterm data from the re-deployment cruises three and six months into the experiment. The basin data will first be processed for the pulse arrival structure as a function of transmission time. Similarly, motion compensation will have to be applied in the processing. Using these pulse responses, time series of transmission loss and of travel times of individual arrivals will be derived, and then their multi-scale variability analyzed. In addition to characterizing the annual acoustic variability, the basin data will be employed to help monitor the transbasin internal tides and wave packets using standard tomography techniques. To achieve this, a ray-based propagation model, after calibrated by the sonobuoy-transect data, will be used to simulate the eigenrays and the "reference" arrival structure. Identification of the ray arrivals, followed by inversion of the reciprocal travel-time data, will then be performed.

WORK COMPLETED

The shelf experiment was successfully completed in April 2005. In it, a moored source, a moored vertical line hydrophone array, moored temperature strings and a towed Scanfish CTD were employed to obtain simultaneous measurements of the fluctuating acoustic signal intensity and of the variable sound speeds for a period of three days. Other U.S. and Taiwan acousticians contributed additional and highly complementary acoustic measurements with autonomous mobile acoustic sources (MAS), sonobuoys, and a bottom-mounted hydrophone (BMH).

The basin experiment began in April 2005 and will end in May 2006. It entails seasonal cruises to maintain two moored acoustic transceivers that reciprocally and periodically transmit a signal across the basin. Additionally, during the deployment cruise for the basin moorings, sonobuoys were systematically dropped along the transmission path to measure transmission loss versus range.

In addition to carrying out the aforementioned experiments, work completed in FY05 includes (1) processed all phase-encoded acoustic signals measured by the VLA in the shelf experiment for time series of the pulse arrival structure, (2) analyzed the temperature string data from the shelf experiment for sound-speed mean and internal wave-induced perturbation spatial and temporal structures, and (3) processed and analyzed the sonobuoy-transect data for an initial estimate of the transmission loss (TL) across the basin.

RESULTS

Only results from the shelf experiment are reported here as the basin experiment is still ongoing. Figure 1 shows the experimental configuration of the shelf experiment, depicting the types of instruments that were deployed, except for the Scanfish CTD that was towed along the fixed-fixed transmission paths. Figure 2 shows the sound-speed time series observed at a depth of 60 m by four separate temperature strings spanning the Source-to-VLA transmission path. Tidal and high-frequency variations evolving shoreward are clearly observed. While the former was associated with diurnal internal tides, the latter was produced primarily by elevation internal waves that caused large decreases in sound speed. Note that depression internal waves were occasionally observed along the transmission path, particularly at moments when the isotherms were significantly displayed upward by the internal tides, causing the thickness of the lower water layer to become larger than the thickness of the upper layer.

Figure 3 shows some of the processed/analyzed acoustics results. The right panels show two VLA receptions of the same signal transmitted by the moored sound source at two different times. These two receptions clearly show a very different vertical distribution of the acoustic energy resulting from the sound-speed fluctuations induced by the nonlinear internal waves. The mean sound-speed profile was range-independent and downward refracting. Thus, in the absence of the nonlinear internal waves, it is anticipated that the measured sound field is dominated by the low-loss, low acoustic modes that are trapped to the lower water-column. This dominance by low modes, however, was often suppressed or reversed due to strong scattering of low-mode energy to the higher modes resulting from the presence of the nonlinear internal waves.

The right panel of Figure 3 shows a time series of the relative signal intensity measured by one of the hydrophones of the VLA. This hydrophone was located at a depth of 65 m. Intensity fluctuations induced by the internal tides and high-frequency internal waves are clearly seen. It is important to note that the observed intensity changes with the diurnal period were not due to mode coupling. Rather,

they were a consequence of a cyclic decrease and increase of loss to the bottom as the internal tides alternately stretched and compressed the sound channel.

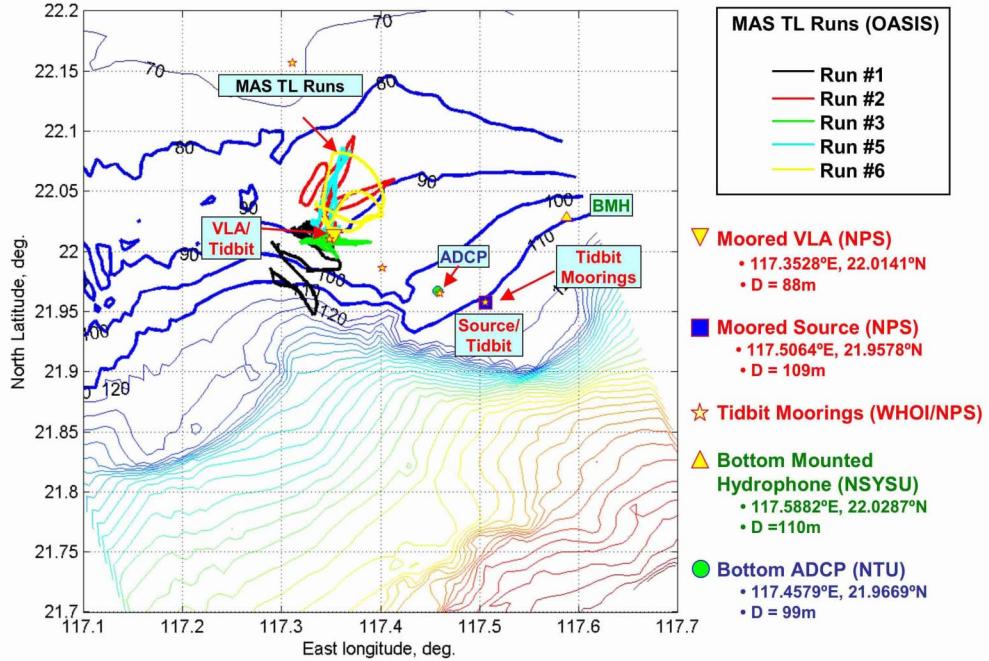


Figure 1. Experimental configuration of the shelf experiment carried out in April 2005.

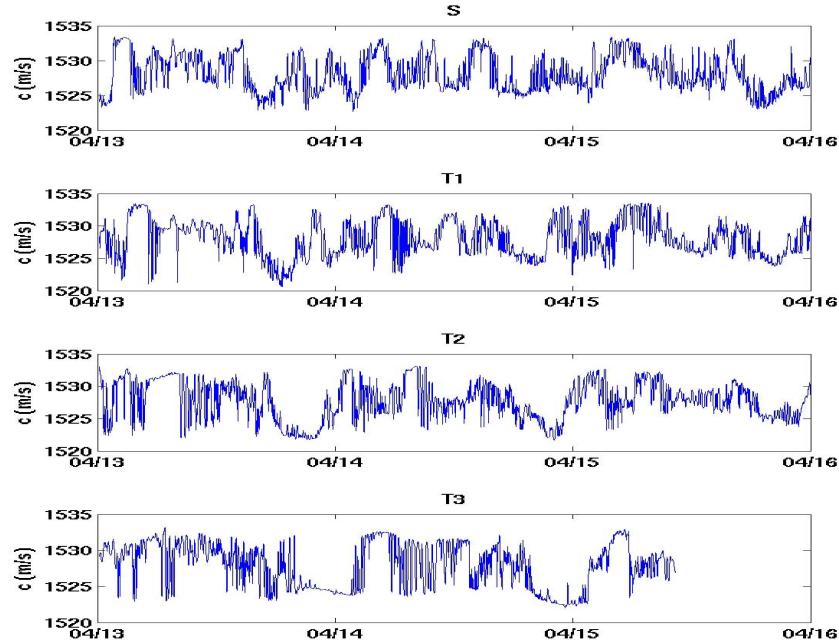


Figure 2. Sound speed changes at 60 m measured by SeaBird thermistors moored along the source-to-VLA transmission path.

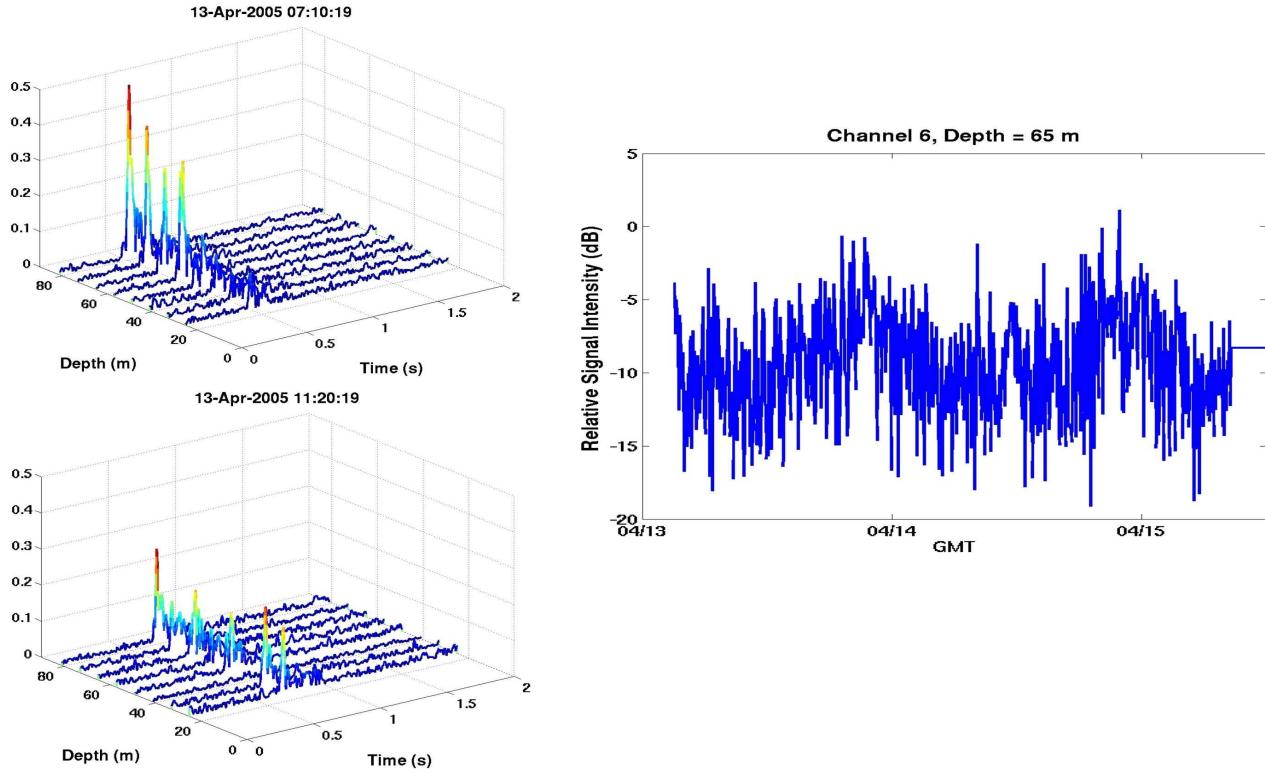


Figure 3. Fixed-fixed transmission initial results. The left panels show two snapshots of the processed VLA receptions showing changes in the vertical distribution of the acoustic energy. The right panel shows the measured relative signal intensity versus time at 65 m.

IMPACT/APPLICATIONS

The oceanographic and acoustic data gathered in this field study should be valuable in helping to create models of shelfbreak regions suitable for assessing present and future Navy systems, acoustic as well as non-acoustic.

RELATED PROJECT

This fully integrated acoustics and oceanography experiment should significantly extend the findings and data from SWARM, Shelfbreak PRIMER and ASIAEX, thus improving our knowledge of the physics, variability, geographical dependence and predictability of sound propagation in a shelf-slope environment.

PUBLICATION

Schneck-Scott, A.R., "Detection and Resolvability of Pulsed Acoustic Signals through the South China Sea Basin: A Modeling Analysis," Naval Postgraduate School Master Thesis, September 2005.